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Matsuyama

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(54) **EXCAVATION CONTROL SYSTEM AND CONSTRUCTION MACHINE**

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(51) **Int. Cl.**

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E02F 3/30	(2006.01)
E02F 9/22	(2006.01)
E02F 9/26	(2006.01)

(52) **U.S. Cl.**
CPC . ***E02F 3/435*** (2013.01); ***E02F 3/30*** (2013.01); ***E02F 3/437*** (2013.01); ***E02F 9/2203*** (2013.01); ***E02F 9/262*** (2013.01); ***E02F 9/265*** (2013.01)

(58) **Field of Classification Search**
CPC E02F 3/435; E02F 3/437; E02F 3/30
USPC 701/50
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2005/0027420 A1 2/2005 Fujishima et al.

FOREIGN PATENT DOCUMENTS

EP 1 541 772 A1 6/2005
JP 8-134949 A 5/1996

(Continued)

OTHER PUBLICATIONS

International Search Report for PCT/JP2012/0052686 issued on May 15, 2012.

(Continued)

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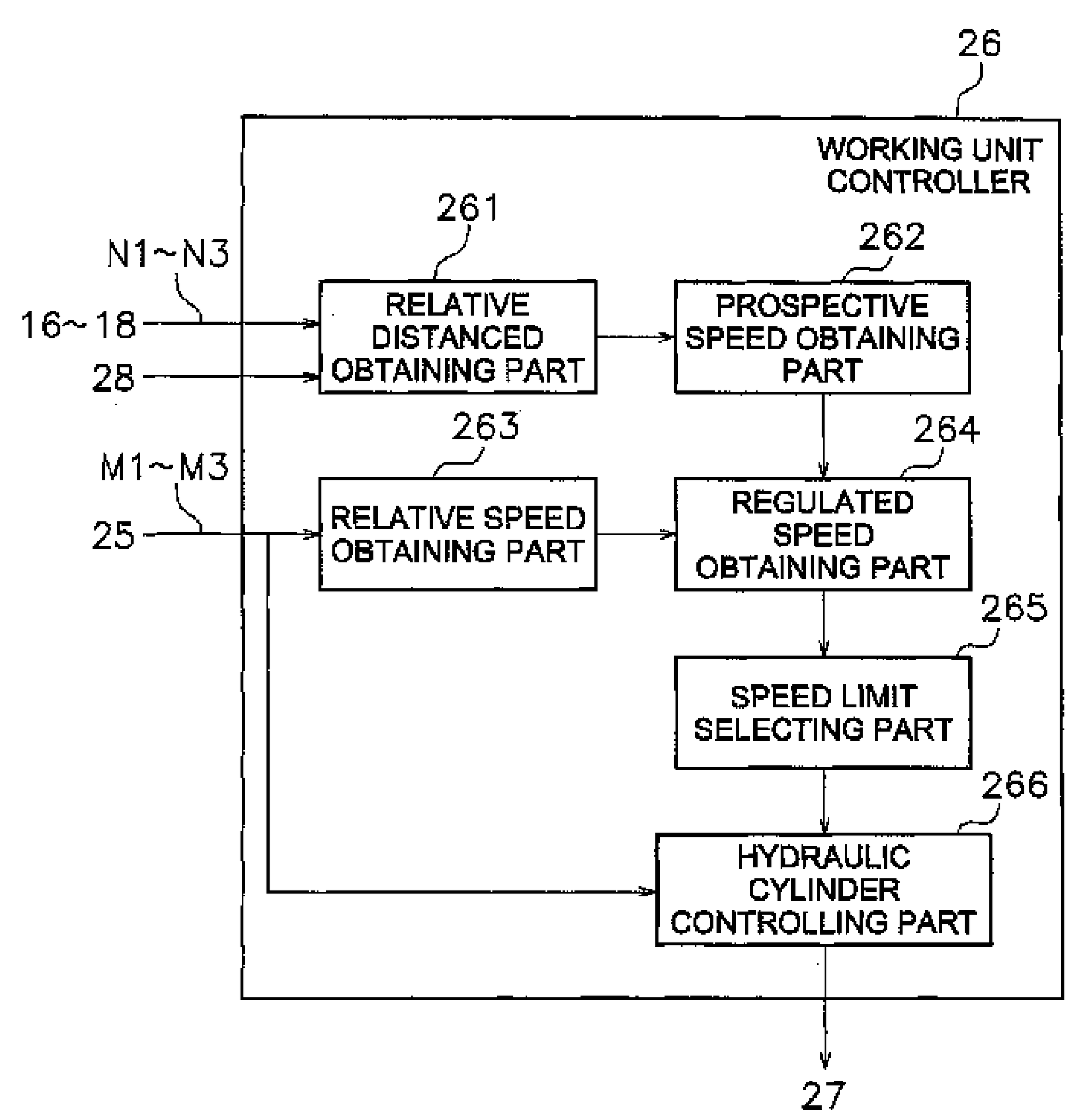
(74) *Attorney, Agent, or Firm* — Global IP Counselors, LLP

(57) **ABSTRACT**

An excavation control system includes a working unit, hydraulic cylinders, a prospective speed obtaining part, a speed limit selecting part and a hydraulic cylinder controlling art. The prospective speed part is configured to obtain a first prospective speed depending on a first distance between the bucket and a first designed surface, and a second prospective speed depending on a second distance between the bucket and a second designed surface. The speed limit selecting part is configured to select one of the first and second prospective speeds as a speed limit based on a relative relation between the first designed surface and the bucket and a relative relation between the second designed surface and the bucket. The hydraulic cylinder controlling part is configured to limit a relative speed of the bucket relative to one of the first and second designed surfaces to the speed limit.

18 Claims, 10 Drawing Sheets



(56) **References Cited**

FOREIGN PATENT DOCUMENTS

JP	2006-265954	A		10/2006
JP	2006265954	A	*	10/2006
JP	2008-106440	A		5/2008
JP	2009-179968	A		8/2009
WO	95/30059	A1		11/1995

OTHER PUBLICATIONS

The Office Action for the corresponding German patent application No. 11 2012 001 013.2, issued on Mar. 12, 2015.

The Office Action for the corresponding Korean patent application No. 10-2013-7020979, issued on Jan. 26, 2015.

* cited by examiner

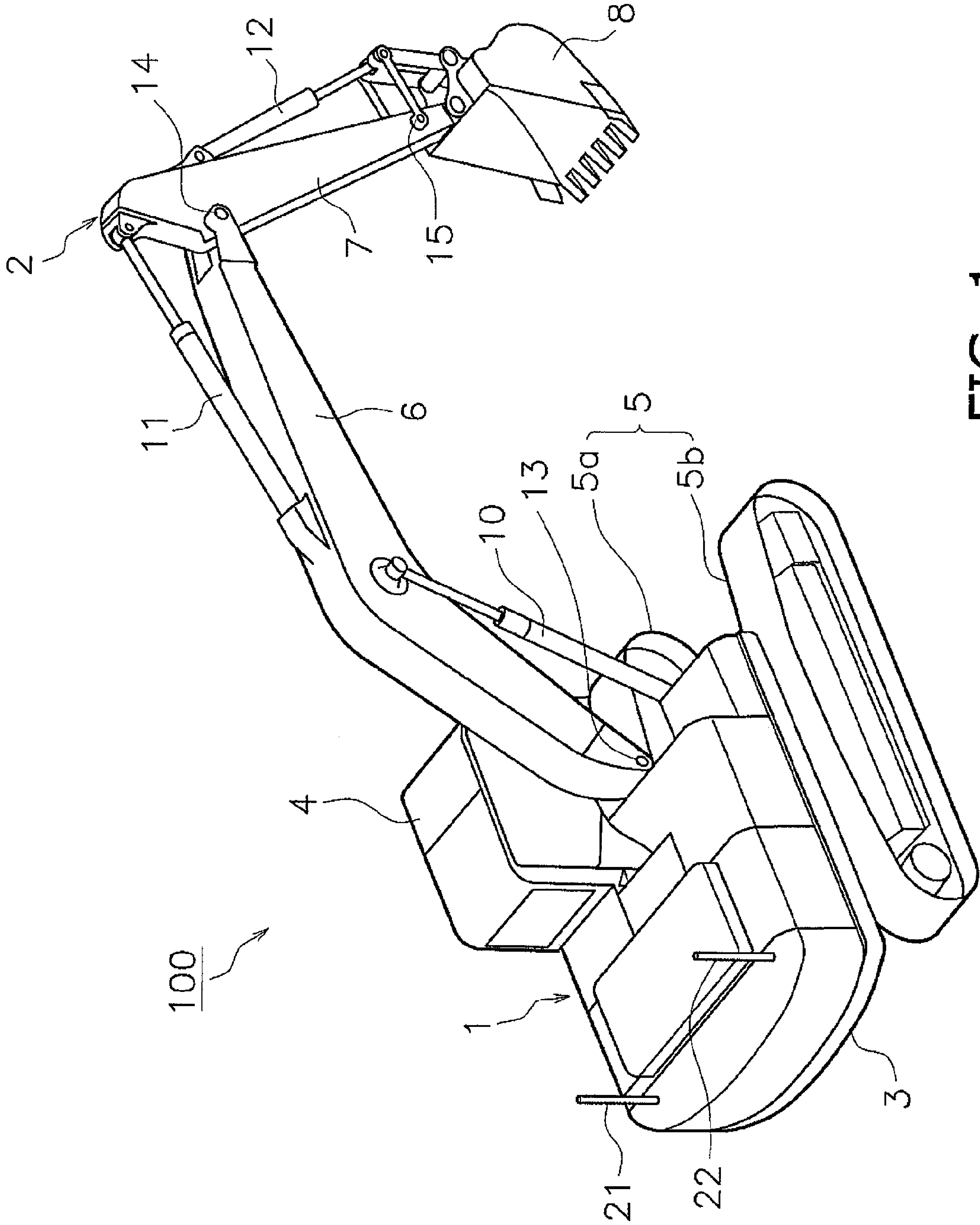


FIG. 1

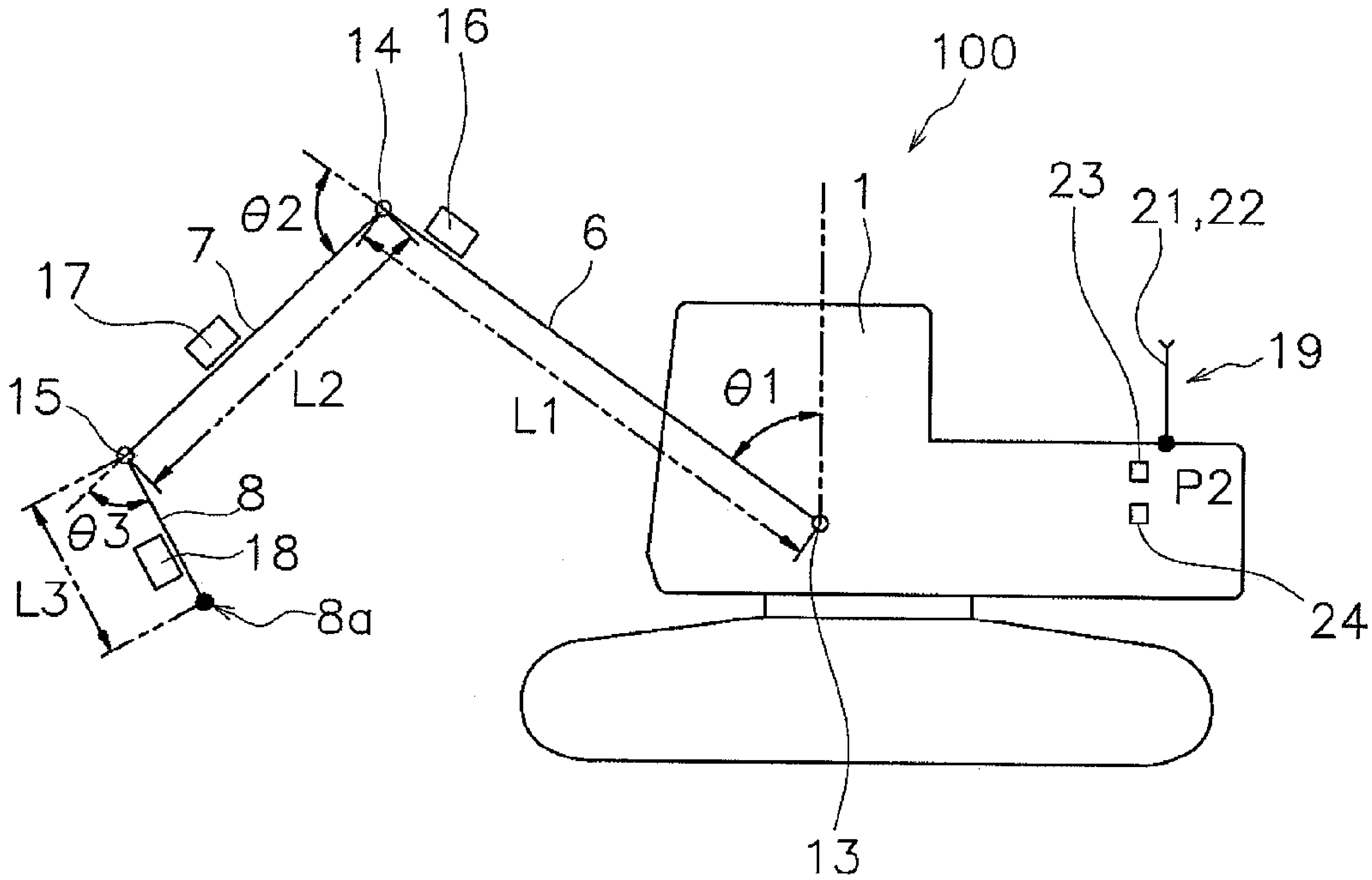

14
16
100
θ2
23
21,22
1
7
6
17
19
θ1
L2
15
L1
P2
8
θ3
18
L3
8a
24
13

FIG. 2A

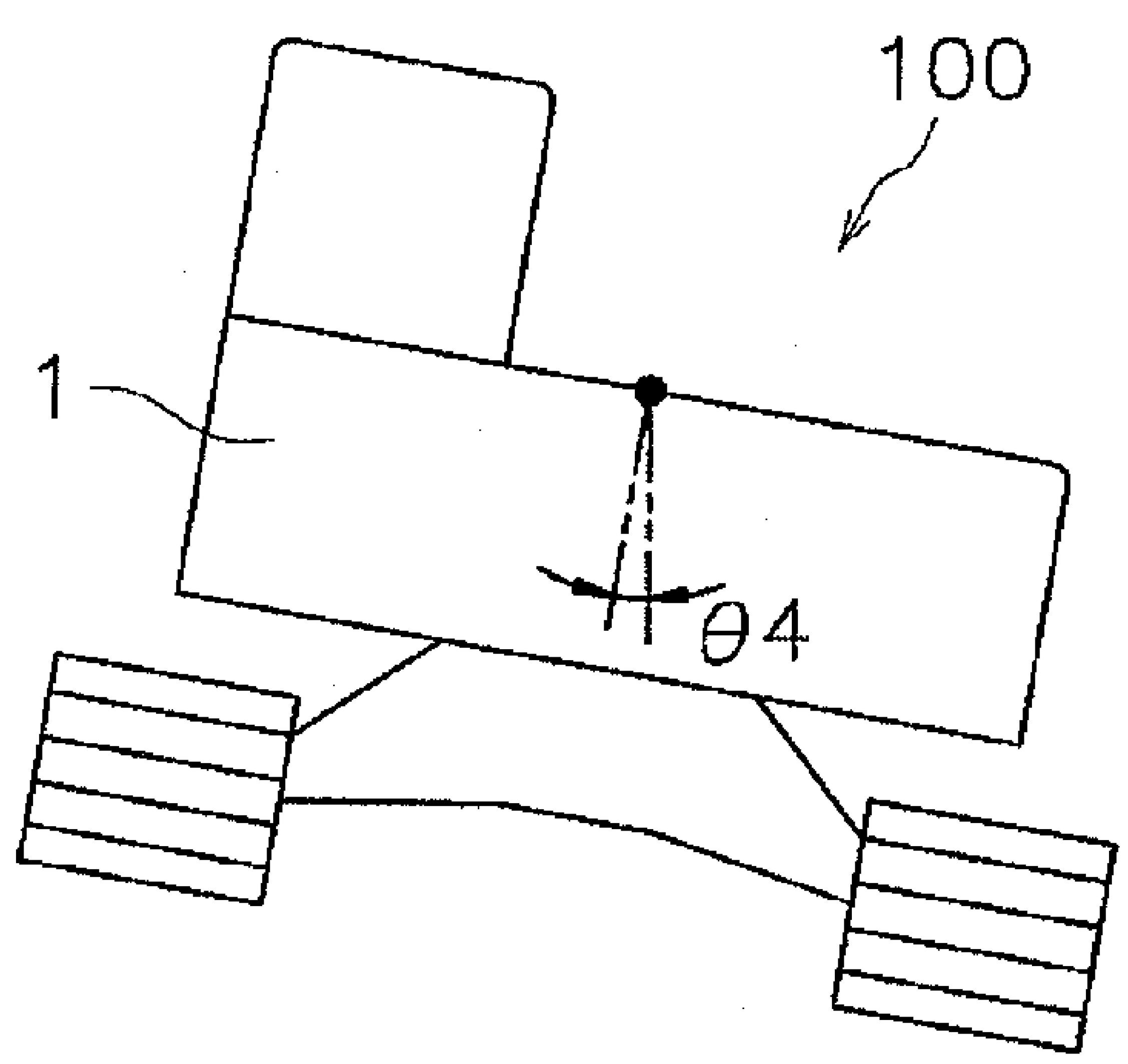

100
1
θ4

FIG. 2B

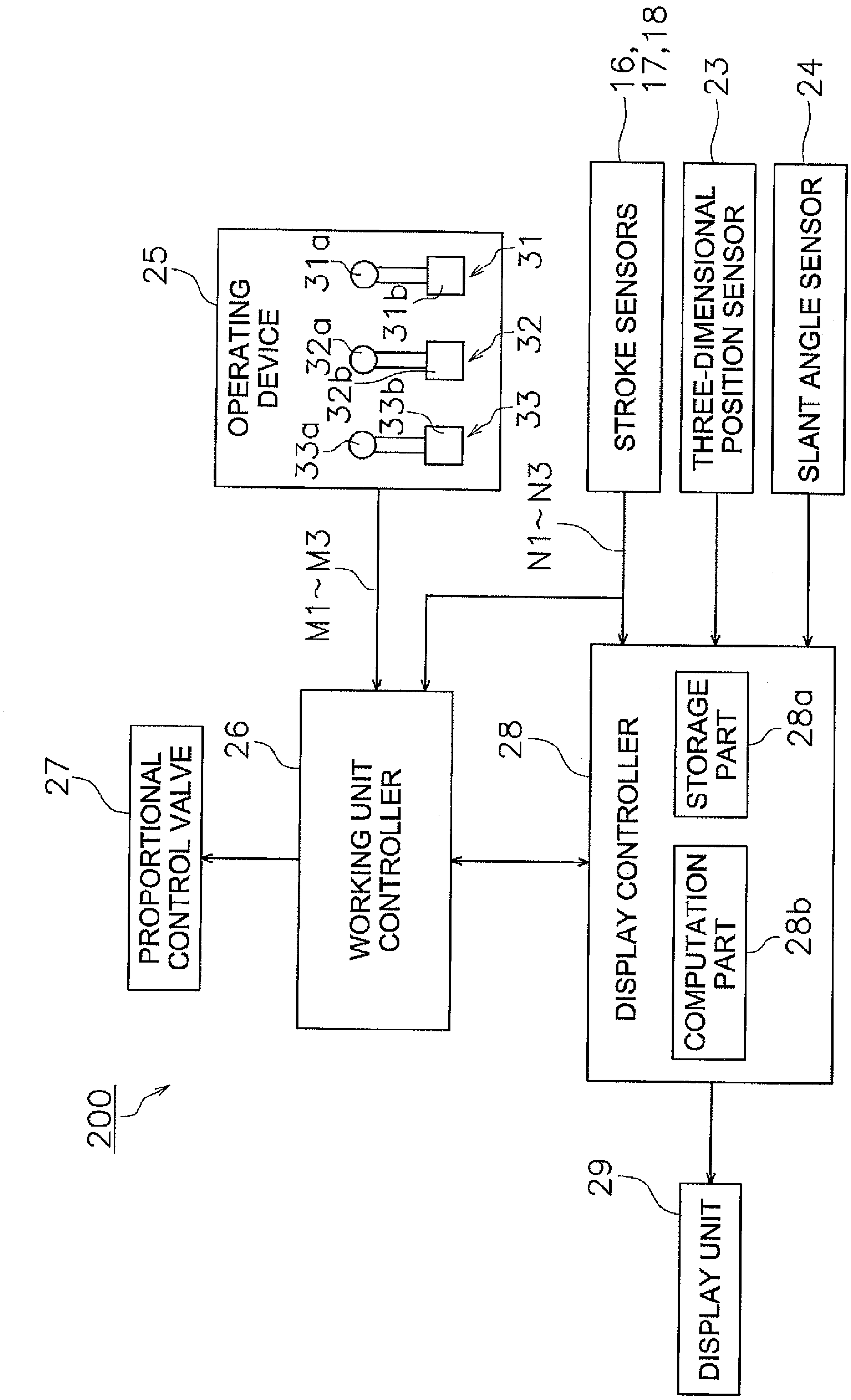

200
27
PROPORTIONAL CONTROL VALVE
26
WORKING UNIT CONTROLLER
25
OPERATING DEVICE
31a
31b
31
32a
32b
32
33a
33b
33
M1~M3
N1~N3
16, 17, 18
STROKE SENSORS
23
THREE-DIMENSIONAL POSITION SENSOR
24
SLANT ANGLE SENSOR
28
DISPLAY CONTROLLER
STORAGE PART
28a
COMPUTATION PART
28b
29
DISPLAY UNIT

FIG. 3

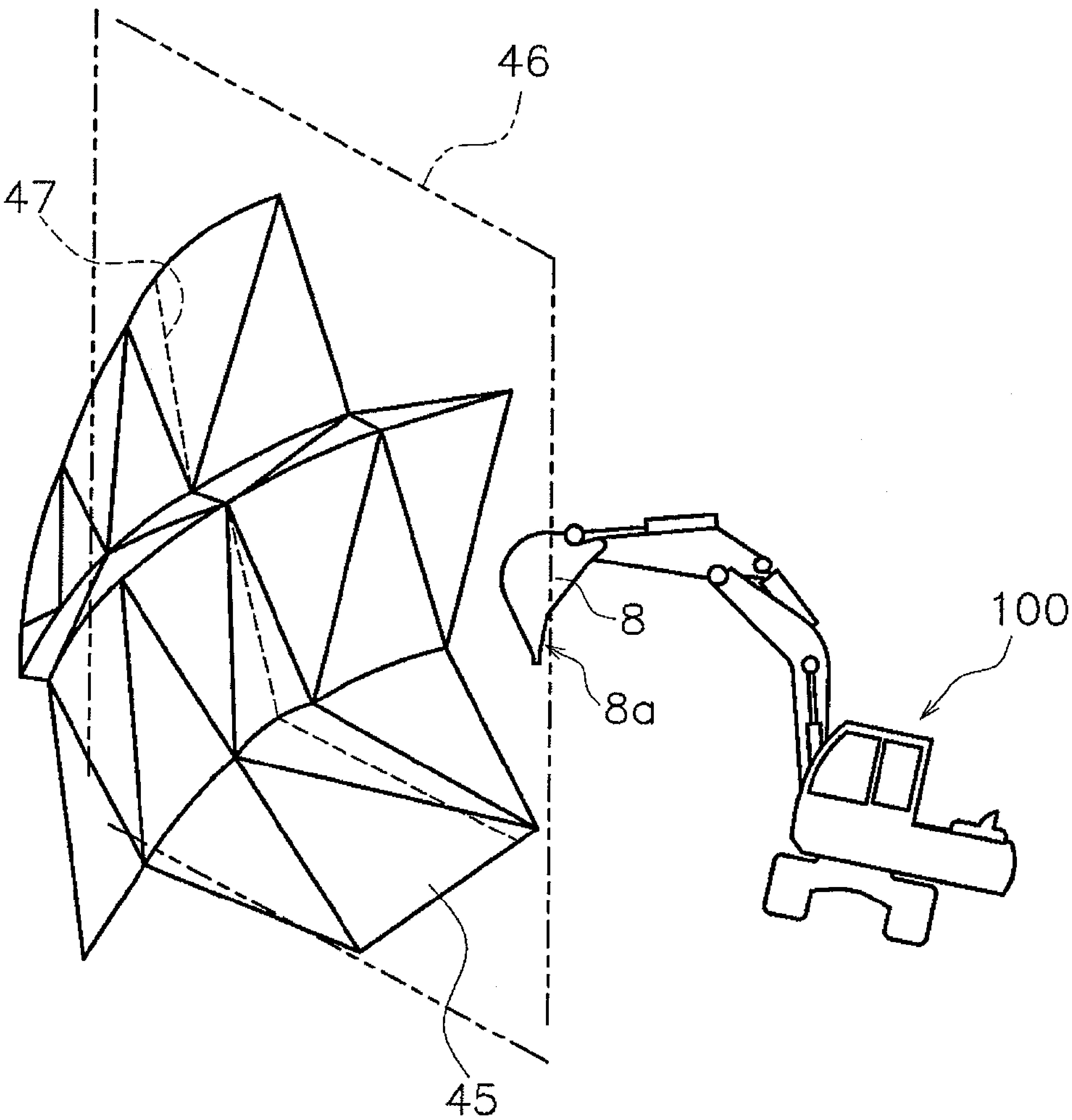


FIG. 4

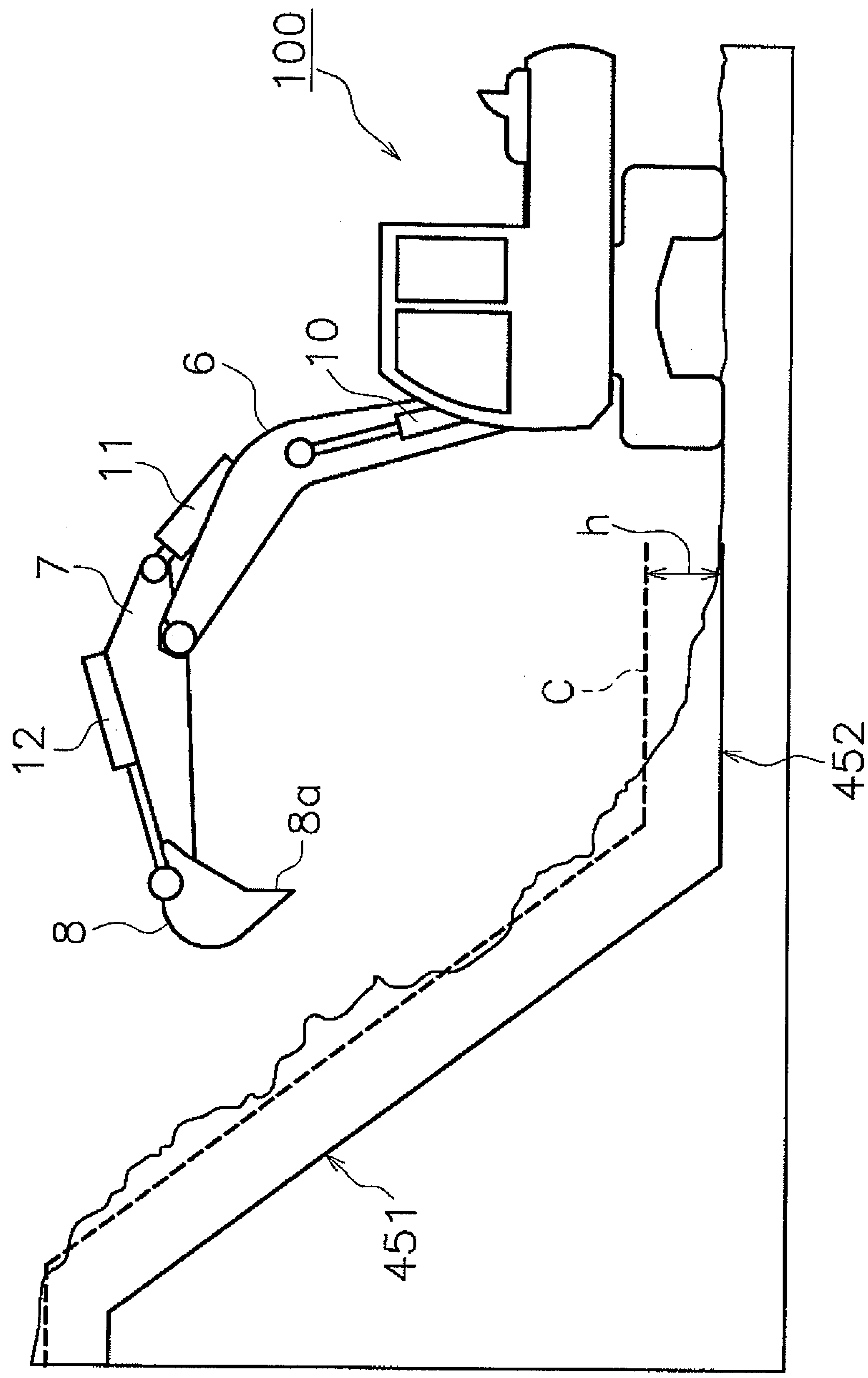


FIG. 5

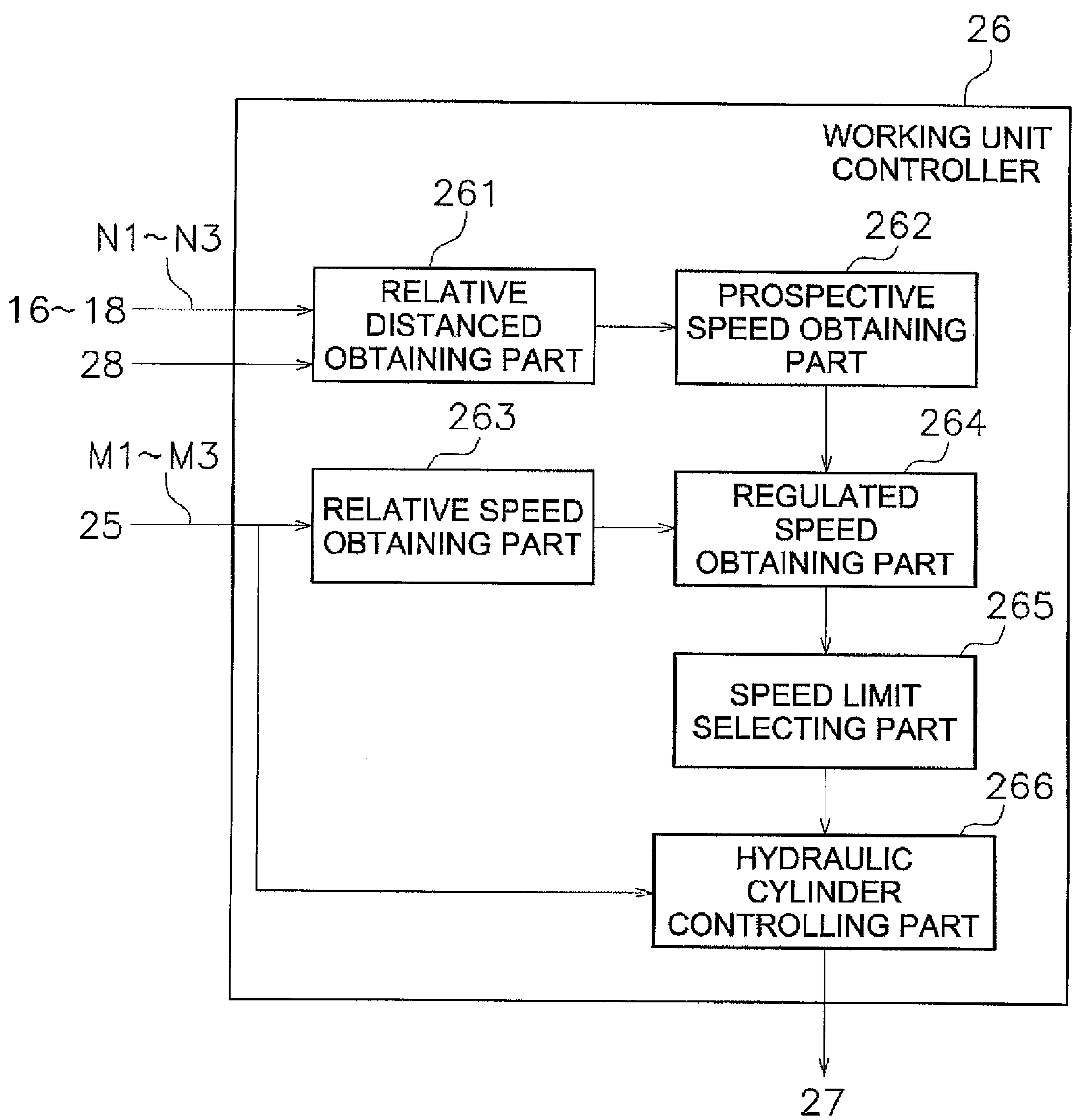

26
WORKING UNIT CONTROLLER
261
N1~N3
16~18
28
RELATIVE DISTANCED OBTAINING PART
262
PROSPECTIVE SPEED OBTAINING PART
263
M1~M3
25
RELATIVE SPEED OBTAINING PART
264
REGULATED SPEED OBTAINING PART
265
SPEED LIMIT SELECTING PART
266
HYDRAULIC CYLINDER CONTROLLING PART
27

FIG. 6

FIG. 7

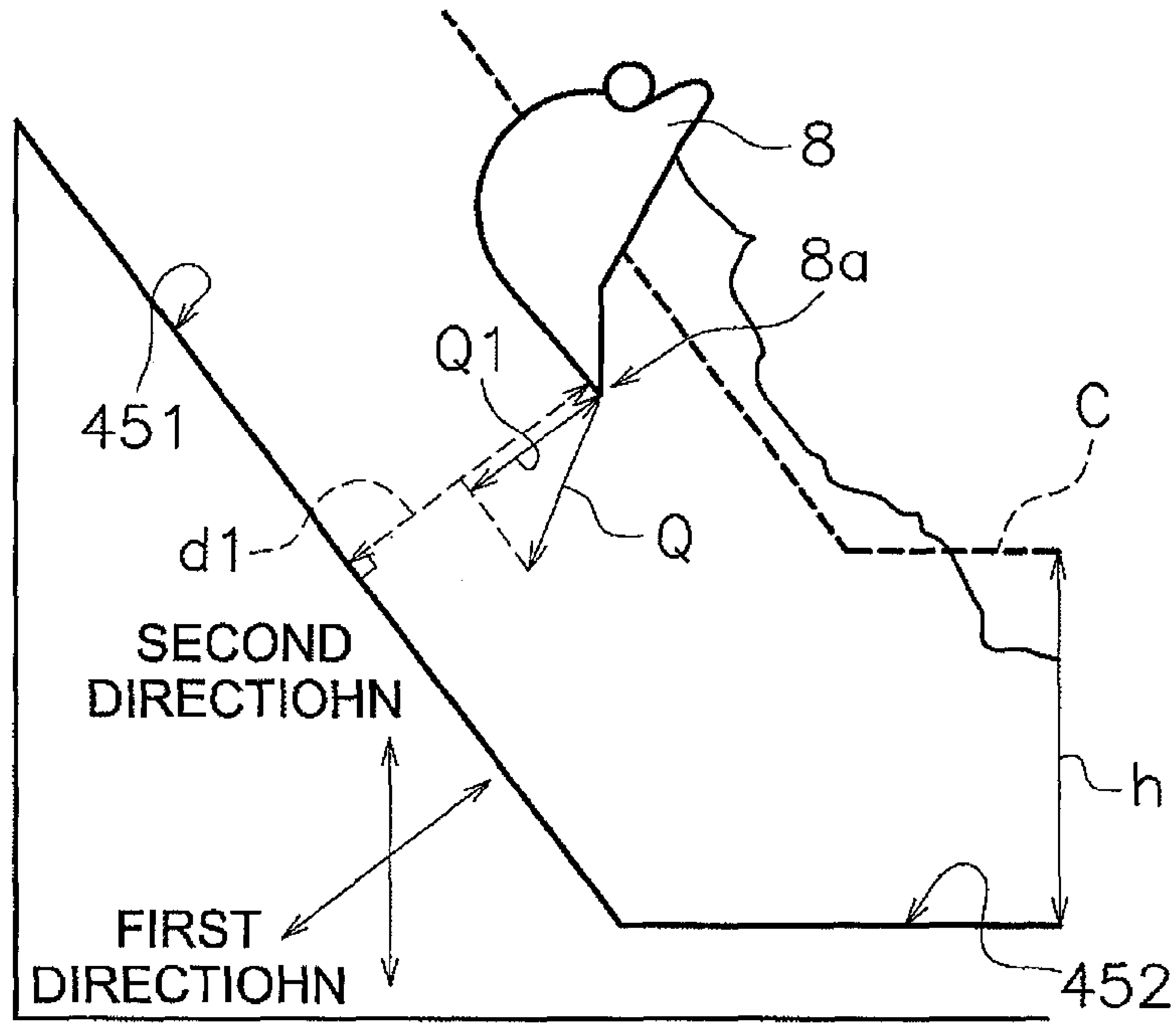

8
8a
Q1
451
C
d1
Q
SECOND
DIRECTIOHN
h
FIRST
DIRECTIOHN
452

FIG. 8

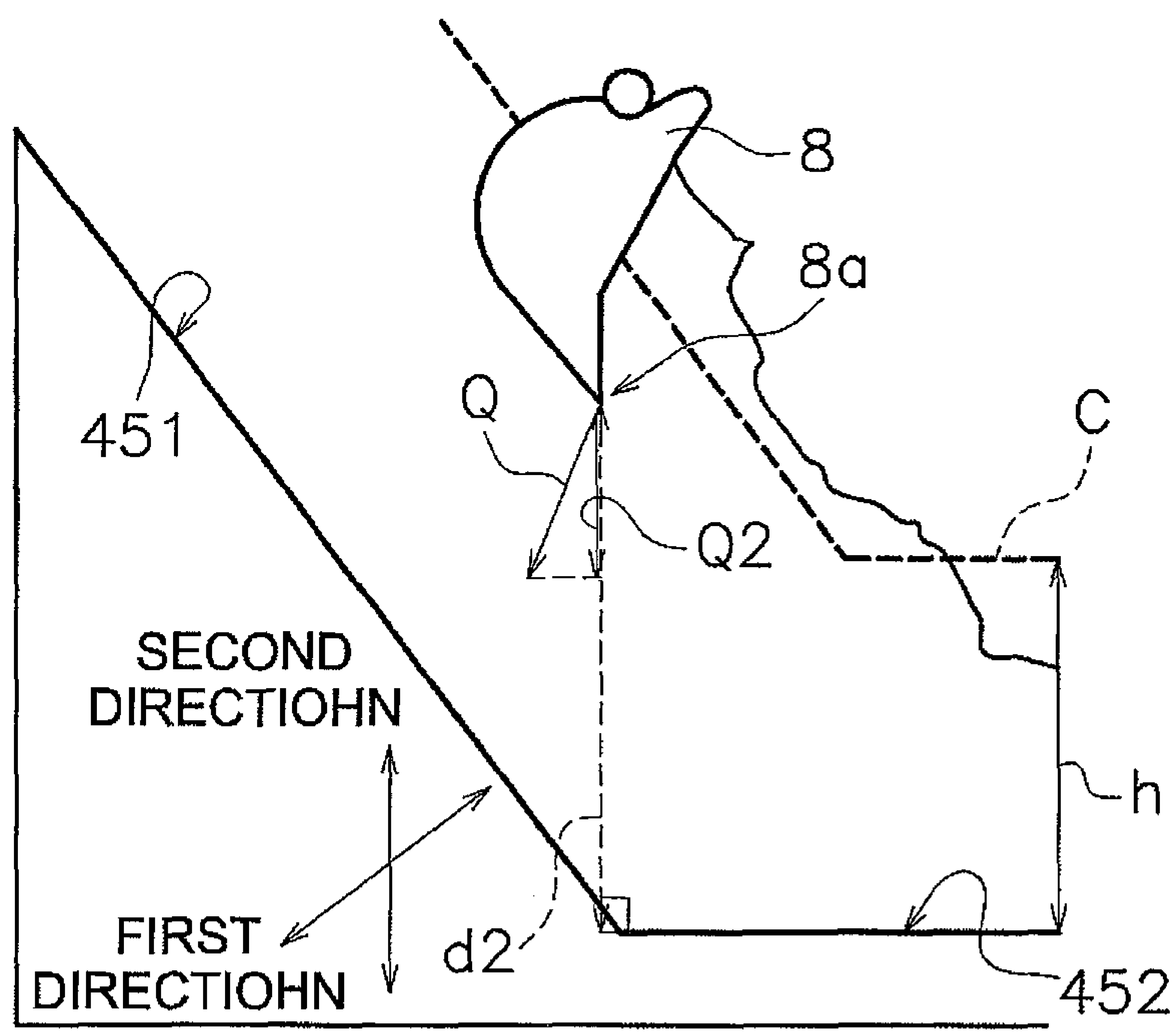

8
8a
Q
451
C
Q2
SECOND
DIRECTIOHN
h
FIRST
DIRECTIOHN
d2
452

FIG. 9

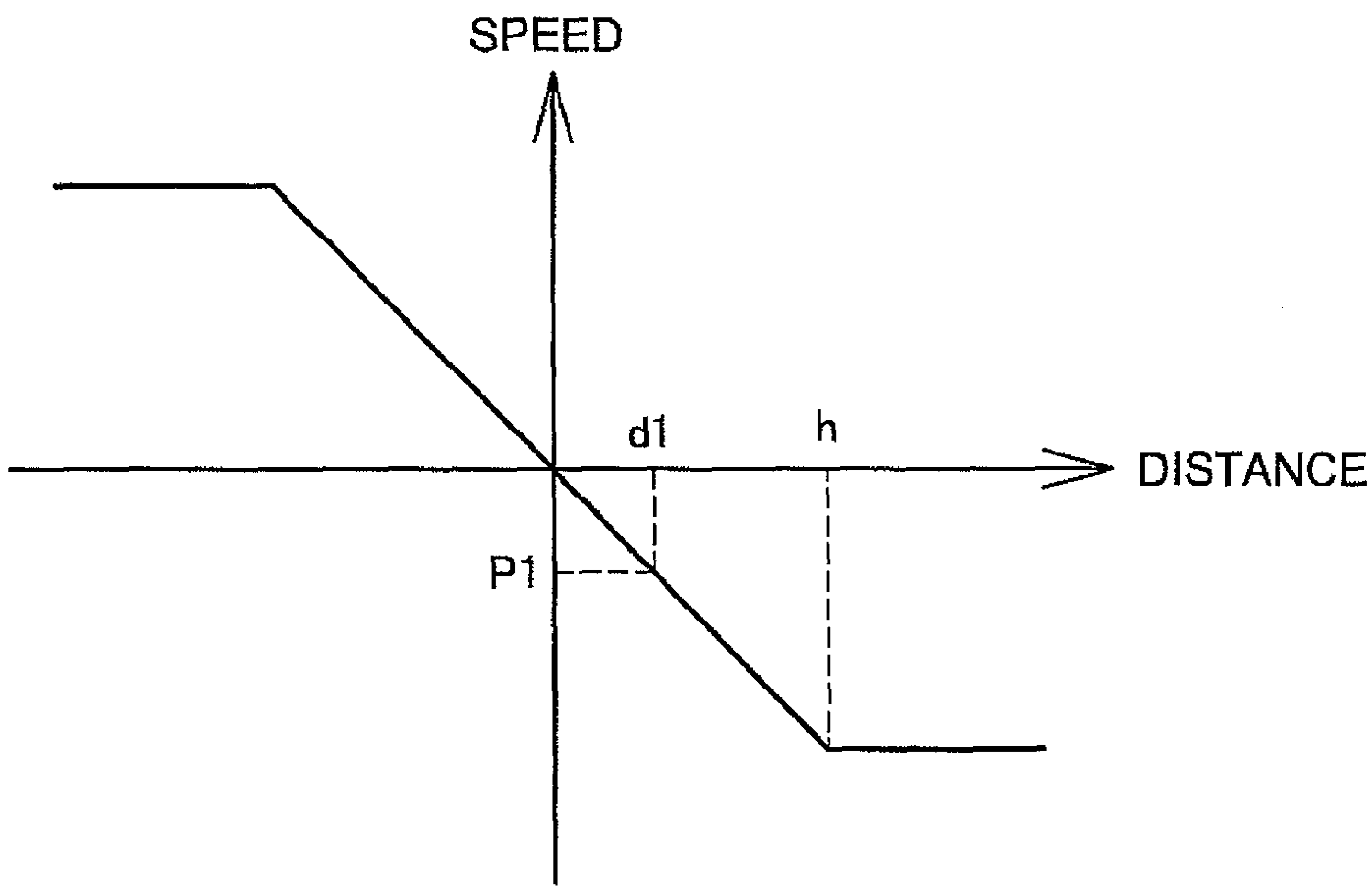


FIG. 10

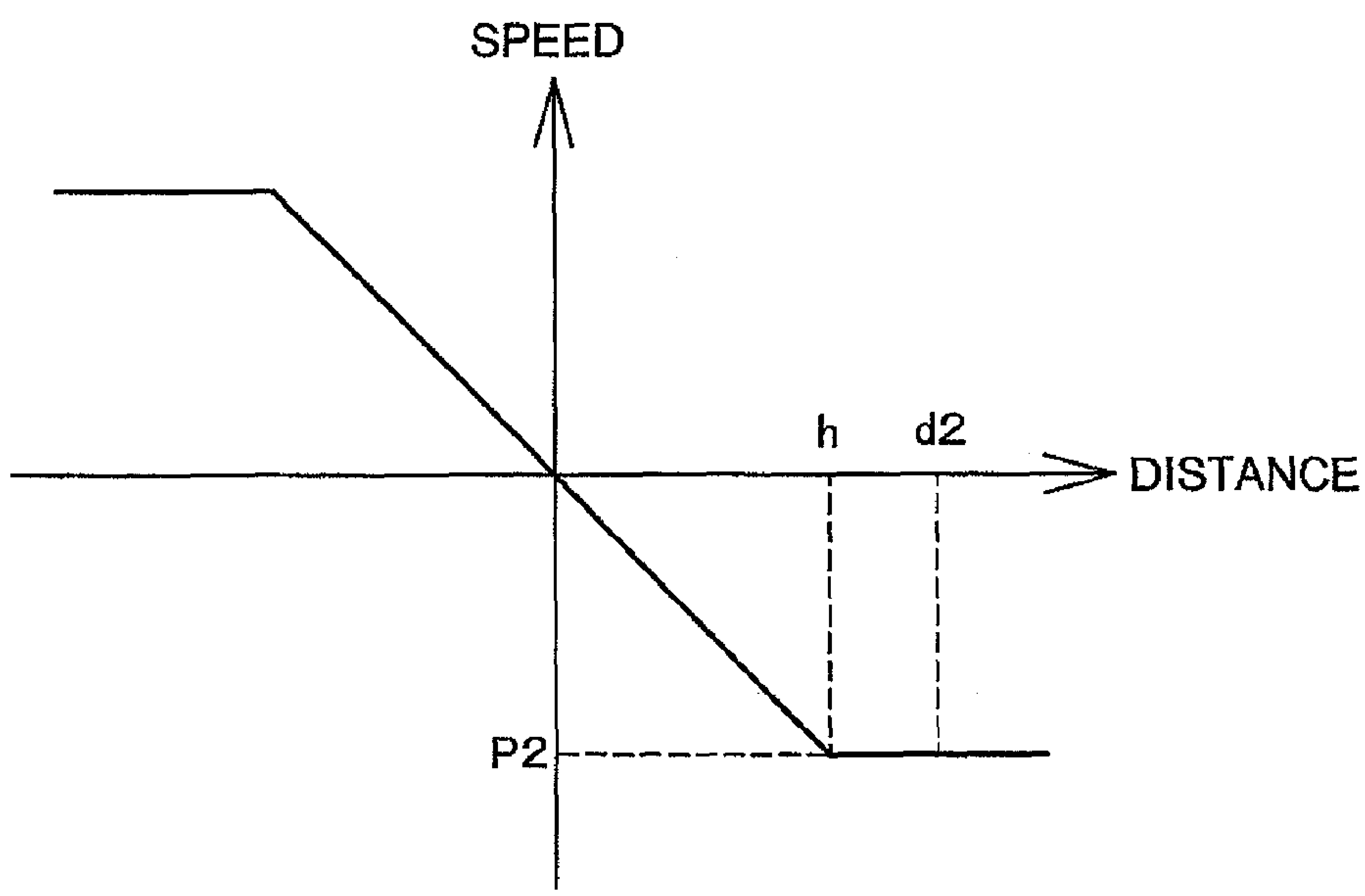


FIG. 11

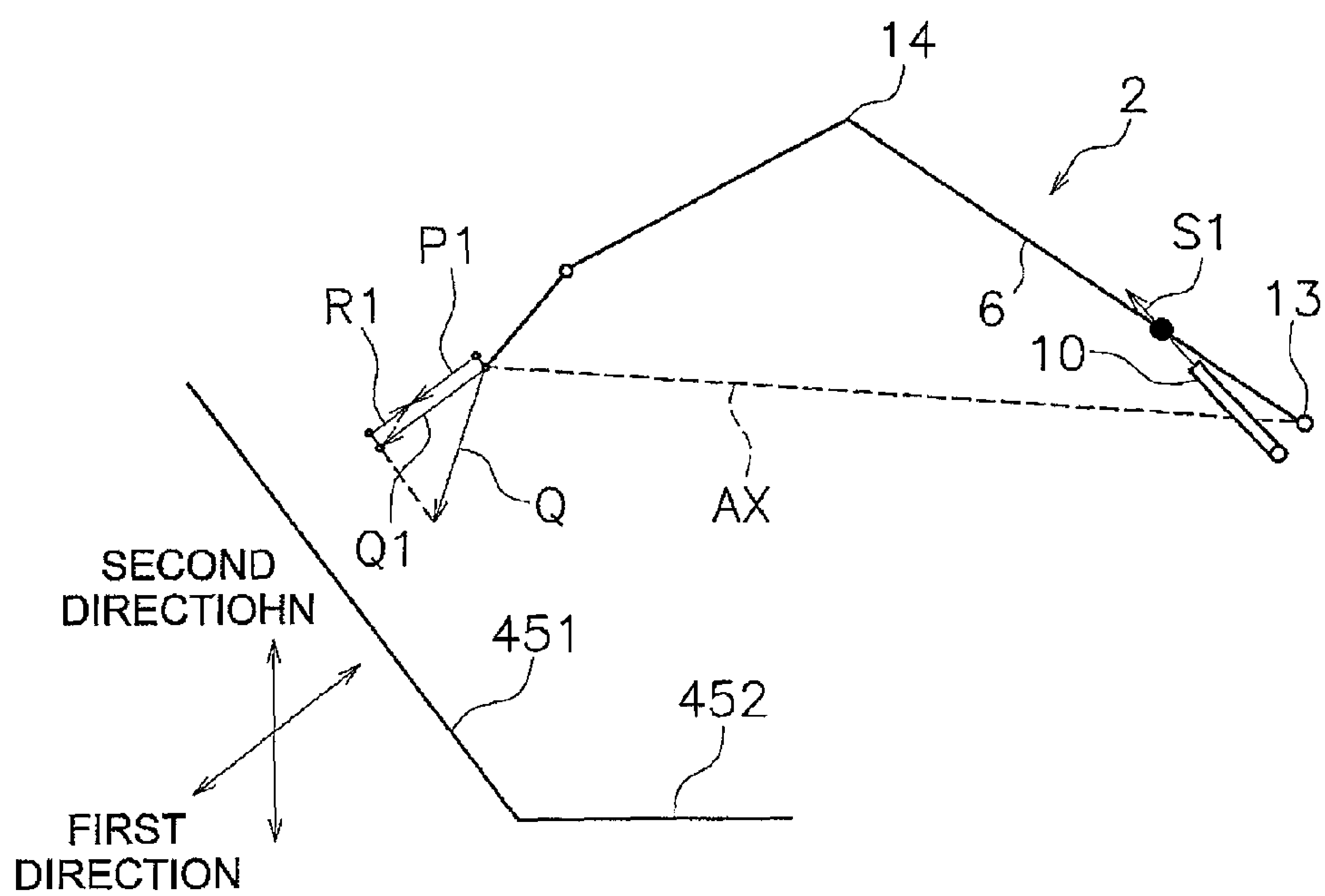
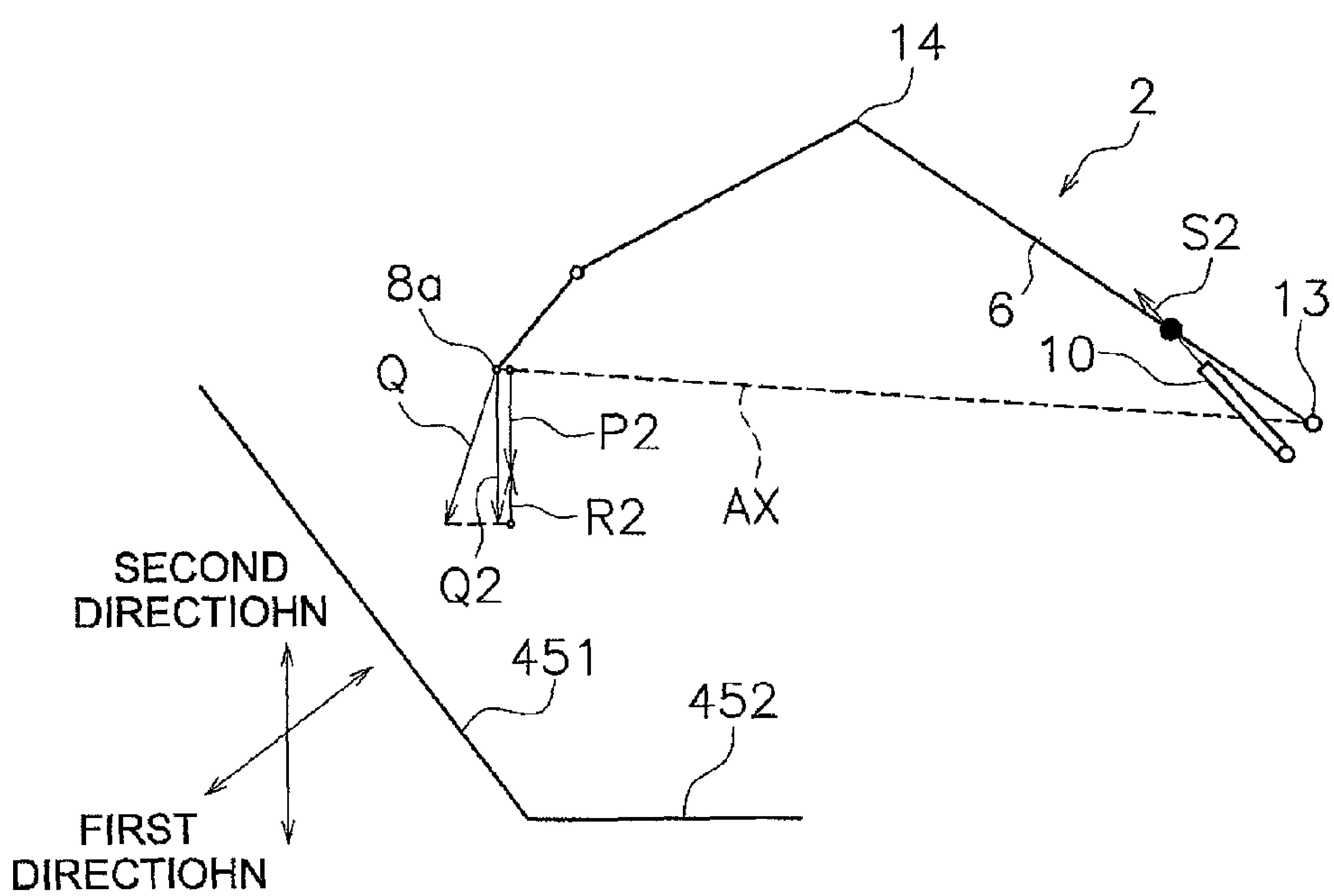

14
2
P1
S1
R1
6
13
10
Q
AX
Q1
SECOND
DIRECTIOHN
451
452
FIRST
DIRECTION

FIG. 12


14
2
S2
8a
6
13
10
Q
P2
R2
AX
Q2
SECOND
DIRECTIOHN
451
452
FIRST
DIRECTIOHN

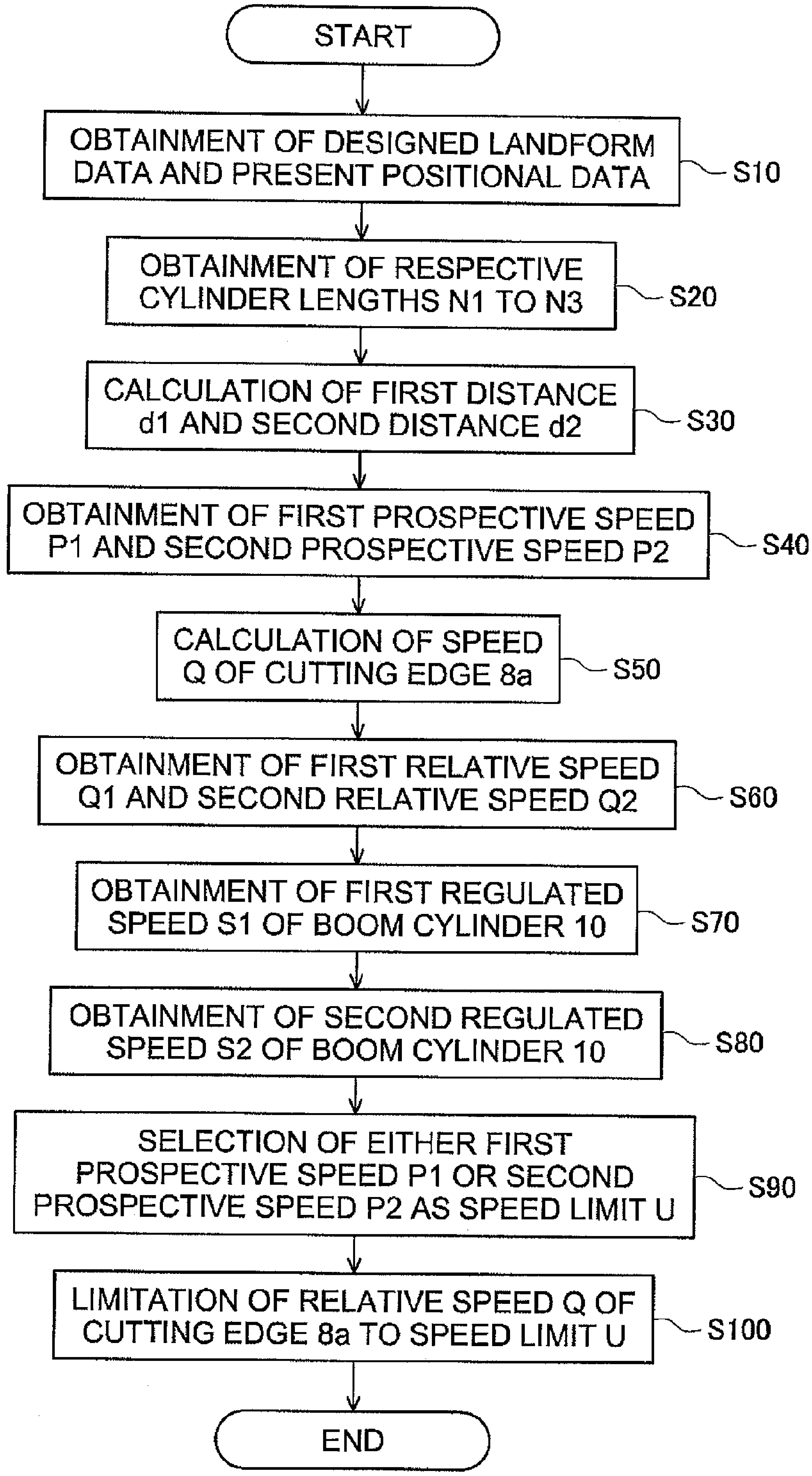

START
OBTAINMENT OF DESIGNED LANDFORM DATA AND PRESENT POSITIONAL DATA
S10
OBTAINMENT OF RESPECTIVE CYLINDER LENGTHS N1 TO N3
S20
CALCULATION OF FIRST DISTANCE d1 AND SECOND DISTANCE d2
S30
OBTAINMENT OF FIRST PROSPECTIVE SPEED P1 AND SECOND PROSPECTIVE SPEED P2
S40
CALCULATION OF SPEED Q OF CUTTING EDGE 8a
S50
OBTAINMENT OF FIRST RELATIVE SPEED Q1 AND SECOND RELATIVE SPEED Q2
S60
OBTAINMENT OF FIRST REGULATED SPEED S1 OF BOOM CYLINDER 10
S70
OBTAINMENT OF SECOND REGULATED SPEED S2 OF BOOM CYLINDER 10
S80
SELECTION OF EITHER FIRST PROSPECTIVE SPEED P1 OR SECOND PROSPECTIVE SPEED P2 AS SPEED LIMIT U
S90
LIMITATION OF RELATIVE SPEED Q OF CUTTING EDGE 8a TO SPEED LIMIT U
S100
END

FIG. 13

EXCAVATION CONTROL SYSTEM AND CONSTRUCTION MACHINE

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims priority to Japanese Patent Application No. 2011-066825, filed on Mar. 24, 2011, the disclosure of which is hereby incorporated herein by reference in its entirety.

BACKGROUND

1. Field of Invention

The present invention relates to an excavation control system configured to impose a limitation on the speed of a working unit and a construction machine including the excavation control system.

2. Background Information

For a construction machine equipped with a working unit, a method has been conventionally known that a predetermined region is excavated by moving a bucket along a designed surface indicating a target shape for an excavation object (see PCT International Publication No. WO95/30059).

Specifically, a control device in PCT International Publication No. WO95/30059 is configured to correct an operation signal to be inputted by an operator so that the relative speed of the bucket relative to the designed surface is reduced as an interval is reduced between the bucket and the designed surface. Thus, an excavation control of automatically moving the bucket along the designed surface is executed by imposing a limitation on the speed of the bucket.

SUMMARY

However, according to the excavation control described in PCT International Publication No. WO95/30059, in excavating first and second designed surfaces located adjacently to each other, the second designed surface cannot be recognized while an excavation work is executed along the first designed surface. Therefore, chances are that the second designed surface is damaged.

The present invention has been produced in view of the aforementioned situation, and is intended to provide an excavation control system capable of appropriately executing an excavation control relative to a plurality of designed surfaces and a construction machine.

An excavation control system according to a first aspect includes a working unit, a plurality of hydraulic cylinders, a prospective speed obtaining part, a speed limit selecting part and a hydraulic cylinder controlling part. The working unit is formed by a plurality of driven members including a bucket, and is rotatably supported by a vehicle main body. The plurality hydraulic cylinders are configured to drive the plurality of driven members. The prospective speed obtaining part is configured to obtain a first prospective speed and a second prospective speed, the first prospective speed depending on a first distance between the bucket and a first designed surface indicating a target shape for an excavation object, and the second prospective speed depends on a second distance between the bucket and a second designed surface indicating a target shape for the excavation target, and the second designed surface is set differently from the first designed surface. The speed limit selecting part is configured to select either of the first prospective speed or the second prospective speed as a speed limit based on a relative relation between the first designed surface and the bucket and a relative relation between the second designed surface and the bucket. The hydraulic cylinder controlling part is configured to limit a relative speed of the bucket to the speed limit, and the relative speed is relative to either one designed surface of the first and second designed surfaces which is a target of the speed limit.

An excavation control system according to a second aspect relates to the excavation control system according to the first aspect, and further includes a relative speed obtaining part. The relative speed obtaining part is configured to obtain a first relative speed of the bucket relative to the first designed surface and a second relative speed of the bucket relative to the second designed surface. The speed limit selecting part is configured to select the speed limit based on a relative relation between the first relative speed and the first prospective speed and a relative relation between the second relative speed and the second prospective speed.

An excavation control system according to a third aspect relates to the excavation control system according to the first aspect, and wherein the speed limit selecting part is configured to select the speed limit based on the first distance and the second distance.

It is possible to provide an excavation control system appropriately capable of executing an excavation control with respect to a plurality of designed surfaces and a construction machine.

BRIEF DESCRIPTION OF DRAWINGS

FIG. **1** is a perspective view of a hydraulic excavator **100**.

FIG. **2**A is a side view of the hydraulic excavator **100**.

FIG. **2**B is a rear view of the hydraulic excavator **100**.

FIG. **3** is a block diagram representing a functional configuration of an excavation control system **200**.

FIG. **4** is a schematic diagram illustrating an exemplary designed landform to be displayed on a display unit **29**.

FIG. **5** is a cross-sectional view of the designed landform taken along an intersected line **47**.

FIG. **6** is a block diagram representing a configuration of a working unit controller **26**.

FIG. **7** is a schematic diagram representing a positional relation between a bucket **8** and a first designed surface **451**.

FIG. **8** is a schematic diagram representing a positional relation between the bucket **8** and a second designed surface **452**.

FIG. **9** is a chart representing a relation between a first prospective speed P**1** and a first distance d**1**.

FIG. **10** is a chart representing a relation between a second prospective speed P**2** and a second distance d**2**.

FIG. **11** is a diagram for explaining a method of obtaining a first regulated speed S**1**.

FIG. **12** is a diagram for explaining a method of obtaining a second regulated speed S**2**.

FIG. **13** is a flowchart for explaining an action of the excavation control system **200**.

DESCRIPTION OF EMBODIMENTS

Explanation will be hereinafter made for an exemplary embodiment of the present invention with reference to the drawings. In the following explanation, a hydraulic excavator will be explained as an example of "construction machine".

Overall Structure of Hydraulic Excavator **100**

FIG. **1** is a perspective view of a hydraulic excavator **100** according to an exemplary embodiment. The hydraulic excavator **100** includes a vehicle main body **1** and a working unit

2. Further, the hydraulic excavator **100** is embedded with an excavation control system **200**. Explanation will be made below for a configuration and an action of the excavation control system **200**.

The vehicle main body **1** includes an upper revolving unit **3**, a cab **4** and a drive unit **5**. The upper revolving unit **3** accommodates an engine, a hydraulic pump and so forth (not illustrated in the figures). A first GNSS antenna **21** and a second GNSS antenna **22** are disposed on the rear end part of the upper revolving unit **3**. The first GNSS antenna **21** and the second GNSS antenna **22** are antennas for RTK-GNSS (Real Time Kinematic—GNSS, note GNSS refers to Global Navigation Satellite Systems). The cab **4** is mounted on the front part of the upper revolving unit **3**. An operating device **25** to be described is disposed within the cab **4** (see FIG. **3**). The drive unit **5** includes crawler belts **5***a* and **5***b*, and circulation of the crawler belts **5***a* and **5***b* enables the hydraulic excavator **100** to travel.

The working unit **2** is attached to the front part of the vehicle main body **1**, and includes a boom **6**, an arm **7**, a bucket **8**, a boom cylinder **10**, an arm cylinder **11** and a bucket cylinder **12**. The base end of the boom **6** is pivotally attached to the front part of the vehicle main body **1** through a boom pin **13**. The base end of the arm **7** is pivotally attached to the tip end of the boom **6** through an arm pin **14**. The bucket **8** is pivotally attached to the tip end of the arm **7** through a bucket pin **15**.

The boom cylinder **10**, the arm cylinder **11** and the bucket cylinder **12** are respectively hydraulic cylinders to be driven by means of an operating oil. The boom cylinder **10** is configured to drive the boom **6**. The arm cylinder **11** is configured to drive the arm **7**. The bucket cylinder **12** is configured to drive the bucket **8**.

Now, FIG. **2**A is a side view of the hydraulic excavator **100**, whereas FIG. **2**B is a rear view of the hydraulic excavator **100**. As illustrated in FIG. **2**A, the length of the boom **6**, i.e., the length from the boom pin **13** to the arm pin **14** is L**1**. The length of the arm **7**, i.e., the length from the arm pin **14** to the bucket pin **15** is L**2**. The length of the bucket **8**, i.e., the length from the bucket pin **15** to the tip ends of teeth of the bucket **8** (hereinafter referred to as "a cutting edge **8***a*") is L**3**.

Further, as illustrated in FIG. **2**A, the boom **6**, the arm **7** and the bucket **8** are provided with first to third stroke sensors **16** to **18** on a one-to-one basis. The first stroke sensor **16** is configured to detect the stroke length of the boom cylinder **10** (hereinafter referred to as "a boom cylinder length N**1**"). Based on the boom cylinder length N**1** detected by the first stroke sensor **16**, a display controller **28** to be described (see FIG. **3**) is configured to calculate a slant angle θ**01** of the boom **6** with respect to the vertical direction in the Cartesian coordinate system of the vehicle main body. The second stroke sensor **17** is configured to detect the stroke length of the arm cylinder **11** (hereinafter referred to as "an arm cylinder length N**2**"). Based on the arm cylinder length N**2** detected by the second stroke sensor **17**, the display controller **28** is configured to calculate a slant angle θ**2** of the arm **7** with respect to the boom **6**. The third stroke sensor **18** is configured to detect the stroke length of the bucket cylinder **12** (hereinafter referred to as "a bucket cylinder length N**3**"). Based on the bucket cylinder length N**3** detected by the third stroke sensor **18**, the display controller **28** is configured to calculate a slant angle θ**3** of the cutting edge **8***a* included in the bucket **8** with respect to the arm **7**.

The vehicle main body **1** is equipped with a position detecting unit **19**. The position detecting unit **19** is configured to detect the present position of the hydraulic excavator **100**. The position detecting unit **19** includes the aforementioned first and second GNSS antennas **21** and **22**, a three-dimensional position sensor **23** and a slant angle sensor **24**. The first and second GNSS antennas **21** and **22** are disposed while being separated at a predetermined distance in the vehicle width direction. Signals in accordance with GNSS radio waves received by the first and second GNSS antennas **21** and **22** are configured to be inputted into the three-dimensional position sensor **23**. The three-dimensional position sensor **23** is configured to detect the installation positions of the first and second GNSS antennas **21** and **22**. As illustrated in FIG. **2**B, the slant angle sensor **24** is configured to detect a slant angle θ**4** of the vehicle main body **1** in the vehicle width direction with respect to a gravity direction (a vertical line).

Configuration of Excavation Control System **200**

FIG. **3** is a block diagram representing a functional configuration of the excavation control system **200**. The excavation control system **200** includes the operating device **25**, a working unit controller **26**, a proportional control valve **27**, the display controller **28** and a display unit **29**.

The operating device **25** is configured to receive an operator operation to drive the working unit **2** and is configured to output an operation signal in accordance with the operation of the operator. Specifically, the operating device **25** includes a boom operating tool **31**, an arm operating tool **32** and a bucket operating tool **33**. The boom operating tool **31** includes a boom operating lever **31***a* and a boom operation detecting part **31***b*. The boom operating lever **31***a* receives an operation of the boom **6** by the operator. The boom operation detecting part **31***a* is configured to output a boom operation signal M**1** in response to an operation of the boom operating lever **31***a*. An arm operating lever **32***a* receives an operation of the arm **7** by the operator. An arm operation detecting part **32***b* is configured to output an arm operation signal M**2** in response to an operation of the arm operating lever **32***a*. The bucket operating tool **33** includes a bucket operating lever **33***a* and a bucket operation detecting part **33***b*. The bucket operating lever **33***a* receives an operation of the bucket **8** by the operator. The bucket operation detecting part **33***b* is configured to output a bucket operation signal M**3** in response to an operation of the bucket operating lever **33***a*.

The working unit controller **26** is configured to obtain the boom operation signal M**1**, the arm operation signal M**2** and the bucket operation signal M**3** from the operating device **25**. The working unit controller **26** is configured to obtain the boom cylinder length N**1**, the arm cylinder length N**2** and the bucket cylinder length N**3** from the first to third stroke sensors **16** to **18**, respectively. The working unit controller **26** is configured to output control signals based on the aforementioned various pieces of information to the proportional control valve **27**. Accordingly, the working unit controller **26** is configured to execute an excavation control of automatically moving the bucket **8** along a plurality of designed surfaces **45** (see FIG. **4**). At this time, as described below, the working unit controller **26** is configured to correct the boom operation signal M**1** and then output the corrected boom operation signal M**1** to the proportional control valve **27**. On the other hand, the working unit controller **26** is configured to output the arm operation signal M**2** and the bucket operation signal M**3** to the proportional control valve **27** without correcting the signals M**2** and M**3**. A function and an action of the working unit controller **26** will be described below.

The proportional control valve **27** is disposed among the boom cylinder **10**, the arm cylinder **11**, the bucket cylinder **12** and a hydraulic pump (not illustrated in the figures). The proportional control valve **27** is configured to supply the operating oil at a flow rate set in accordance with the control signal from the working unit controller **26** to each of the boom cylinder **10**, the arm cylinder **11** and the bucket cylinder **12**.

The display controller **28** includes a storage part **28***a* (e.g., a RAM, a ROM, etc.) and a computation part **28***b* (e.g., a CPU, etc.). The storage part **28***a* stores a set of working unit data that contains the aforementioned lengths, i.e., the length L**1** of the boom **6**, the length L**2** of the arm **7** and the length L**3** of the bucket **8**. The set of working unit data contains the minimum value and the maximum value for each of the slant angle θ**1** of the boom **6**, the slant angle θ**2** of the arm **7** and the slant angle θ**3** of the bucket **8**. The display controller **28** can be communicated with the working unit controller **26** by means of wireless or wired communication means. The storage part **28***a* of the display controller **28** has preliminarily stored a set of designed landform data indicating the shape and the position of a three-dimensional designed landform within a work area. The display controller **28** is configured to cause the display unit **29** to display the designed landform based on the designed landform, detection results from the aforementioned various sensors, and so forth.

Now, FIG. **4** is a schematic diagram illustrating an exemplary designed landform to be displayed on the display unit **29**. As illustrated in FIG. **4**, the designed landform is formed by the plurality of designed surfaces **45**, each of which is expressed by a triangular polygon. Each of the plurality of designed surfaces **45** indicates the target shape for an object to be excavated by the working unit **2**. The working unit controller **26** is configured to move the bucket **8** along an intersected line **47** between the plurality of designed surfaces **45** and a plane **46** passing through the present position of the cutting edge **8***a* of the bucket **8**. It should be noted that in FIG. **4**, the reference sign **45** is assigned to only one of the plurality of designed surfaces without being assigned to the others of the plurality of designed surfaces.

FIG. **5** is a cross-sectional view of a designed landform taken along the intersected line **47** and is a schematic diagram illustrating an exemplary designed landform to be displayed on the display unit **29**. As illustrated in FIG. **5**, the designed landform according to the present exemplary embodiment includes a first designed surface **451**, a second designed surface **452** and a speed limitation intervening line C.

The first designed surface **451** is a slope positioned laterally to the hydraulic excavator **100**. The second designed surface **452** is a horizontal plane extended from the bottom end of the first designed surface **451** to the vicinity of the hydraulic excavator **100**. In the present exemplary embodiment, an operator executes excavation along the first designed surface **451** and the second designed surface **452** by moving the bucket **8** from above the first designed surface **451** towards the second designed surface **452**.

The speed limitation intervening line C defines a region in which speed limitation to be described is executed. As described below, when the bucket **8** enters inside from the speed limitation intervening line C, the excavation control system **200** is configured to execute speed limitation. The speed limitation intervening line C is set to be in a position away from each of the first designed surface **451** and the second designed surface **452** at a line distance h. The line distance h is preferably set to be a distance whereby operational feeding of an operator with respect to the working unit **2** is not deteriorated.

Configuration of Working Unit Controller 26

FIG. **6** is a block diagram representing a configuration of the working unit controller **26**. FIG. **7** is a schematic diagram illustrating a positional relation between the bucket **8** and the first designed surface **451**. FIG. **8** is a schematic diagram illustrating a positional relation between the bucket **8** and the second designed surface **452**. FIGS. **7** and **8** illustrate a position of the bucket **8** at the same clock time. It should be noted that explanation will be hereinafter made by focusing on the first designed surface **451** and the second designed surface **452** among the plurality of designed surfaces **45**.

As represented in FIG. **6**, the working unit controller **26** includes a relative distance obtaining part **261**, a prospective speed obtaining part **262**, a relative speed obtaining part **263**, a regulated speed obtaining part **264**, a speed limit selecting part **265** and a hydraulic cylinder controlling part **266**.

As illustrated in FIG. **7**, the relative distance obtaining part **261** is configured to obtain a first distance d**1** between the cutting edge **8***a* and the first designed surface **451** in a first direction perpendicular to the first designed surface **451**. As illustrated in FIG. **8**, the relative distance obtaining part **261** is configured to obtain a second distance d**2** between the cutting edge **8***a* and the second designed surface **452** in a second direction perpendicular to the second designed surface **452**. The relative distance obtaining part **261** is configured to calculate the first distance d**1** and the second distance d**2** based on: the set of designed landform data and the set of present positional data of the hydraulic excavator **100**, which are obtained from the display controller **28**; and the boom cylinder length N**1**, the arm cylinder length N**2** and the bucket cylinder length N**3**, which are obtained from the first to third stroke sensors **16** to **18**. The relative distance obtaining part **261** is configured to output the first distance d**1** and the second distance d**2** to the prospective speed obtaining part **262**. It should be noted that in the present exemplary embodiment, the first distance d**1** is less than the second distance d**2**.

The prospective speed obtaining part **262** is configured to obtain: a first prospective speed P**1** set in accordance with the first distance d**1**; and a second prospective speed P**2** set in accordance with the second distance d**2**. The first prospective speed P**1** is herein a speed set in accordance with the first distance d**1** in a uniform manner. As represented in FIG. **9**, the first prospective speed P**1** is maximized where the first distance d**1** is greater than or equal to the line distance h, and gets slower as the first distance d**1** becomes less than the line distance h. Likewise, the second prospective speed P**2** is a speed set in accordance with the second distance d**2** in a uniform manner. As represented in FIG. **10**, the second prospective speed P**2** is maximized where the second distance d**2** is greater than or equal to the line distance h, and gets slower as the second distance d**2** becomes less than the line distance h. The prospective speed obtaining part **262** is configured to output the first prospective speed P**1** and the second prospective speed P**2** to the regulated speed obtaining part **264** and the speed limit selecting part **265**. It should be noted that a direction closer to the first designed surface **451** is a negative direction in FIG. **9**, whereas a direction closer to the second designed surface **452** is a negative direction in FIG. **10**. In the present exemplary embodiment, the first prospective speed P**1** is slower than the second prospective speed P**2**.

The relative speed obtaining part **263** is configured to calculate a speed Q of the cutting edge **8***a* based on the boom operation signal M**1**, the arm operation signal M**2** and the bucket operation signal M**3**, which are obtained from the operating device **25**. Further, as illustrated in FIG. **7**, the relative speed obtaining part **263** is configured to obtain a first relative speed Q**1** of the cutting edge **8***a* with respect to the first designed surface **451** based on the speed Q. As illustrated in FIG. **8**, the relative speed obtaining part **263** is configured to obtain a second relative speed Q**2** of the cutting edge **8***a* with respect to the second designed surface **452** based on the speed Q. The relative speed obtaining part **263** is configured to output the first relative speed Q**1** and the second relative speed Q**2** to the regulated speed obtaining part **264**.

The regulated speed obtaining part **264** is configured to obtain the first prospective speed P**1** from the prospective speed obtaining part **262**, while being configured to obtain the first relative speed Q**1** from the relative speed obtaining part **263**. The regulated speed obtaining part **264** is configured to obtain a first regulated speed S**1** for the extension/contraction speed of the boom cylinder **10**, which is required to limit the first relative speed Q**1** to the first prospective speed P**1**.

Now, FIG. **11** is a diagram for explaining a method of obtaining the first regulated speed S**1**. As illustrated in FIG. **11**, the first relative speed Q**1** is required to be reduced by the amount of a first differential R**1** (=Q**1**−P**1**) in order to suppress the first relative speed Q**1** to the first prospective speed P**1**. On the other hand, the speed of the boom **6** is required to be regulated so that the first differential R**1** can be eliminated from the first relative speed Q**1** only by deceleration in rotational speed of the boom **6** about the boom pin **13**. Accordingly, it is possible to obtain the first regulated speed S**1** based on the first differential R**1**.

Further, the regulated speed obtaining part **264** is configured to obtain the second prospective speed P**2** from the prospective speed obtaining part **262**, while being configured to obtain the second relative speed Q**2** from the relative speed obtaining part **263**. The regulated speed obtaining part **264** is configured to obtain a second regulated speed S**2** for the extension/contraction speed of the boom cylinder **10**, which is required to limit the second relative speed Q**2** to the second prospective speed P**2**.

Now, FIG. **12** is a diagram for explaining a method of obtaining the second regulated speed S**2**. As illustrated in FIG. **12**, the second relative speed Q**2** is required to be reduced by the amount of a second differential R**2** (=Q**2**−P**2**) in order to suppress the second relative speed Q**2** to the second prospective speed P**2**. On the other hand, the speed of the boom **6** is required to be regulated so that the second differential R**2** can be eliminated from the second relative speed Q**2** only by deceleration in rotational speed of the boom **6** about the boom pin **13**. Accordingly, it is possible to obtain the second regulated speed S**2** based on the second differential R**2**.

As illustrated in FIGS. **11** and **12**, in the present exemplary embodiment, the first regulated speed S**1** is set to be greater than the second regulated speed S**2** although the first differential R**1** is equivalent to the second differential R**2**. This is because, when it is attempted to regulate the speed Q of the cutting edge **8***a* by changing the rotational speed of the boom **6** about the boom pin **13**, a speed vector is less easily affected by the change of the rotational speed of the boom **6** as the direction of the speed vector gets closer to a reference line AX (a line connecting the boom pin **13** and the cutting edge **8***a*). In other words, in the present exemplary embodiment, it is more difficult to regulate the first relative speed Q**1** than to change the second relative speed Q**2** by means of changing the rotational speed of the boom **6**.

The speed limit selecting part **265** is configured to obtain the first prospective speed P**1** and the second prospective speed P**2** from the prospective speed obtaining part **262**, while being configured to obtain the first regulated speed S**1** and the second regulated speed S**2** from the regulated speed obtaining part **264**. The speed limit selecting part **265** is configured to select either the first prospective speed P**1** or the second prospective speed P**2** as a speed limit U based on the first regulated speed S**1** and the second regulated speed S**2**. Specifically, the speed limit selecting part **265** is configured to select the first prospective speed P**1** as the speed limit U when the first regulated speed S**1** is greater than the second regulated speed S**2**. By contrast, the speed limit selecting part **265** is configured to select the second prospective speed P**2** as the speed limit U when the second regulated speed S**2** is greater than the first regulated speed S**1**. In the present exemplary embodiment, the first regulated speed S**1** is greater than the second regulated speed S**2**. Therefore, the speed limit selecting part **265** selects the first prospective speed P**1** as the speed limit U.

The hydraulic cylinder controlling part **266** is configured to limit, to the speed limit U, the relative speed Q of the cutting edge **8***a* with respect to the designed surface **45** relevant to the prospective speed P selected as the speed limit U. In the present exemplary embodiment, the hydraulic cylinder controlling part **266** is configured to correct the boom operation signal M**1** and is configured to output the corrected boom operation signal M**1** to the proportional control valve **27** in order to suppress the first relative speed Q**1** to the first prospective speed P**1** only by means of deceleration in rotational speed of the boom **6**. On the other hand, the working unit controller **26** is configured to output the arm operation signal M**2** and the bucket operation signal M**3** to the proportional control valve **27** without correcting the signals M**2** and M**3**.

Accordingly, the flow rates of the operating oil to be supplied to the boom cylinder **10**, the arm cylinder **11** and the bucket cylinder **12** through the proportional control valve **27** are controlled, and the relative speed Q of the cutting edge **8***a* is controlled. In the present exemplary embodiment, the first prospective speed P**1** is selected as the speed limit U. Therefore, the hydraulic cylinder controlling part **266** limits the first relative speed Q**1** of the cutting edge **8***a* to the first prospective speed P**1**.

Action of Excavation Control System 200

FIG. **13** is a flowchart for explaining an action of the excavation control system **200**.

In Step S**10**, the excavation control system **200** obtains the set of designed landform data and the set of present positional data of the hydraulic excavator **100**.

In Step S**20**, the excavation control system **200** obtains the boom cylinder length N**1**, the arm cylinder length N**2** and the bucket cylinder length N**3**.

In Step S**30**, the excavation control system **200** calculates the first distance d**1** and the second distance d**2** based on the set of designed landform data, the set of present positional data, the boom cylinder length N**1**, the arm cylinder length N**2** and the bucket cylinder length N**3** (see FIGS. **7** and **8**).

In Step S**40**, the excavation control system **200** obtains: the first prospective speed P**1** depending on the first distance d**1**; and the second prospective speed P**2** depending on the second distance d**2** (see FIGS. **9** and **10**).

In Step S**50**, the excavation control system **200** calculates the speed Q of the cutting edge **8***a* based on the boom operation signal M**1**, the arm operation signal M**2** and the bucket operation signal M**3** (see FIGS. **7** and **8**).

In Step S**60**, the excavation control system **200** obtains the first relative speed Q**1** and the second relative speed Q**2** based on the speed Q (see FIGS. **7** and **8**).

In Step S**70**, the excavation control system **200** obtains the first regulated speed S**1** for the extension/contraction speed of the boom cylinder **10**, which is required for limiting the first relative speed Q**1** to the first prospective speed P**1** (see FIG. **11**).

In Step **S80**, the excavation control system **200** obtains the second regulated speed **S2** for the extension/contraction speed of the boom cylinder **10**, which is required for limiting the second relative speed Q**2** to the second prospective speed P**2** (see FIG. **12**).

In Step **S90**, the excavation control system **200** selects either the first prospective speed P**1** or the second prospective speed P**2** as the speed limit U based on the first regulated speed S**1** and the second regulated speed S**2**. The excavation control system **200** selects, as the speed limit U, the prospective speed P relevant to the greater one of the first regulated speed S**1** and the second regulated speed S**2**.

In Step **S100**, the excavation control system **200** limits, to the speed limit U, the relative speed Q of the cutting edge **8***a* with respect to the designed surface **45** relevant to the prospective speed P selected as the speed limit U.

Actions and Effects

(1) The excavation control system **200** according to the present exemplary embodiment is configured to obtain: the first regulated speed S**1** for the extension/contraction speed of the boom cylinder **10**, which is required to limit the first relative speed Q**1** to the first prospective speed P**1**; and the second regulated speed S**2** for the extension/contraction speed of the boom cylinder **10**, which is required to limit the second relative speed Q**2** to the second prospective speed P**2**. The excavation control system **200** is configured to select, as the speed limit U, the prospective speed P relevant to the grater one of the first regulated speed S**1** and the second regulated speed S**2**.

Thus, in the excavation control where the first designed surface **451** and the second designed surface **452** exist, speed limitation is executed for the cutting edge **8***a* based on the regulated speed S for the extension/contraction speed of the boom cylinder **10**. Therefore, speed limitation can be executed based on either one of the first designed surface **451** and the second designed surface **452**, which is relevant to the greater regulated speed S for the extension/contraction speed of the boom cylinder **10**.

Here, chances are that regulation for the extension/contraction speed of the boom cylinder **10** is delayed if speed limitation is executed based on a given designed surface **45** relevant to the lesser regulated speed S, and thereafter, speed limitation is executed based on another designed surface **45** relevant to the greater regulated speed S. In this case, excavation cannot be executed according to the designed surface when the cutting edge **8***a* goes beyond the designed surface **45**. Further, shocks inevitably occur due to abrupt driving when regulation of the boom cylinder **10** is forcibly attempted. Therefore, an appropriate excavation control cannot be executed.

By contrast, according to the excavation control system **200** of the present exemplary embodiment, speed limitation is executed based on the designed surface **45** relevant to the greater regulated speed S as described above. Therefore, the boom cylinder **10** can afford to be regulated. It is thereby possible to inhibit the cutting edge **8***a* from going beyond the designed surface **45** and inhibit occurrence of shocks due to abrupt driving. Accordingly, an appropriate excavation control can be executed.

(2) The excavation control system **200** according to the present exemplary embodiment is configured to execute speed limitation by regulating the extension/contraction speed of the boom cylinder **10**.

Therefore, speed limitation is executed by correcting only the boom operation signal M**1** among the operation signals in response to operations by an operator. In other words, among the boom **6**, the arm **7** and the bucket **8**, only the boom **6** is not driven as operated by an operator. Therefore, it is herein possible to inhibit deterioration of operational feeling of an operator in comparison with the configuration of regulating the extension/contraction speeds of two or more driven members among the boom **6**, the arm **7** and the bucket **8**.

Other Embodiments

An exemplary embodiment of the present invention has been explained above. However, the present invention is not limited to the aforementioned exemplary embodiment, and a variety of changes can be made without departing from the scope of the present invention.

(A) In the aforementioned exemplary embodiment, the excavation control system **200** is configured to select, as the speed limit U, either of the first prospective speed P**1** and the second prospective speed P**2** based on the first regulated speed S**1** and the second regulated speed S**2**. However, the present invention is not limited to this. The excavation control system **200** may be configured to select either of the speeds P**1** and P**2** as the speed limit U based on the relative relation between the first designed surface **451** and the bucket **8** and the relative relation between the second designed surface **452** and the bucket **8**. For example, the excavation control system **200** can select either of the speeds P**1** and P**2** as the speed limit U based on the first distance d**1** and the second distance d**2**. In this case, the first prospective speed P**1** may be selected as the speed limit U when the second distance d**2** is less than the first distance d**1**, whereas the second prospective speed P**2** may be selected as the speed limit U when the first distance d**1** is less than the second distance d**2**.

(B) In the aforementioned exemplary embodiment, the excavation control system **200** is configured to execute an excavation control with respect to two of the plurality of designed surfaces **45**, i.e., the first designed surface **451** and the second designed surface **452**. However, the present invention is not limited to this. The excavation control system **200** may be configured to execute an excavation control with respect to three or more designed surfaces **45**. In this case, the excavation control system **200** may be configured to select the speed limit U through the comparison among the regulated speeds S relevant to all the designed surfaces **45**.

(C) In the aforementioned exemplary embodiment, the excavation control system **200** is configured to suppress the relative speed to the speed limit only by deceleration of the rotational speed of the boom **6**. However, the present invention is not limited to this. The excavation control system **200** may be configured to regulate the rotational speed of at least one of the arm **7** and the bucket **8** in addition to the rotational speed of the boom **6**. It is thereby possible to inhibit the speed of the bucket **8** from being reduced in a direction parallel to the designed surface **45** by means of speed limitation. Accordingly, it is possible to inhibit deterioration of operational feeling of an operator. It should be noted that in this case, addition (sum) of the respective regulated speeds of the boom **6**, the arm **7** and the bucket **8** may be calculated as the regulated speed S.

(D) In the aforementioned exemplary embodiment, the excavation control system **200** is configured to calculate the speed Q of the cutting edge **8***a* based on the operation signals M to be obtained from the operating device **25**. However, the present invention is not limited to this. The excavation control system **200** can calculate the speed Q based on variation per unit time for each of the cylinder lengths N**1** to N**3** to be obtained from the first to third stroke sensors **16** to **18**. In this case, the speed Q can be more accurately calculated compared to a configuration of calculating the speed Q based on the operation signals M.

(E) In the aforementioned exemplary embodiment, the excavation control system **200** is configured to execute speed limitation in terms of the speed of the cutting edge **8***a* among the portions of the bucket **8**. However, the present invention is not limited to this. For example, the excavation control system **200** may be configured to execute speed limitation in terms of the speed of the bottom surface among the portions of the bucket **8**.

(F) In the aforementioned exemplary embodiment, as represented in FIGS. **9** and **10**, a linear relation is established between the prospective speed and the distance. However, the present invention is not limited to this. An arbitrary relation may be established between the prospective speed and the distance. Such relation is not necessarily a linear relation, and its relational curve is not required to pass through the origin of its relevant chart.

According to the illustrated embodiments, it is possible to provide a working unit control system capable of appropriately executing an excavation control with respect to a plurality of designed surfaces. Therefore, the control system according to the illustrated embodiments is useful for the field of construction machines.

What is claimed is:

1. An excavation control system comprising:

a working unit formed by a plurality of driven members including a bucket, the working unit being rotatably supported by a vehicle main body;

a plurality of hydraulic cylinders configured to drive the plurality of driven members;

a prospective speed obtaining part configured to obtain a first prospective speed and a second prospective speed, the first prospective speed depending on a first distance between the bucket and a first designed surface indicating a target shape for an excavation object, the second prospective speed depending on a second distance between the bucket and a second designed surface indicating the target shape for the excavation object, the second designed surface being different from the first designed surface, the first designed surface and the second designed surface being disposed adjacent to each other;

a speed limit selecting part configured to select either of the first prospective speed or the second prospective speed as a speed limit based on a relative relation between the first designed surface and the bucket and a relative relation between the second designed surface and the bucket; and

a hydraulic cylinder controlling part configured to limit a relative speed of the bucket to the speed limit, the relative speed being relative to either one designed surface of the first and second designed surfaces which is a target of the speed limit.

2. The excavation control system recited in claim **1**, wherein

the first prospective speed gets slower as the first distance gets shorter, and

the second prospective speed gets slower as the second distance gets shorter.

3. The excavation control system recited in claim **1**, further comprising

a relative speed obtaining part configured to obtain a first relative speed of the bucket relative to the first designed surface and a second relative speed of the bucket relative to the second designed surface, wherein

the speed limit selecting part is configured to select the speed limit based on a relative relation between the first relative speed and the first prospective speed and a relative relation between the second relative speed and the second prospective speed.

4. The excavation control system recited in claim **3**, further comprising

a regulated speed obtaining part configured to obtain a first regulated speed and a second regulated speed, the first regulated speed depending on a target speed for an extension/contraction speed of each of the plurality of hydraulic cylinders which is required to limit the first relative speed to the first prospective speed, the second regulated speed depending on a target speed for an extension/contraction speed of each of the plurality of hydraulic cylinders which is required to limit the second relative speed to the second prospective speed, wherein

the speed limit selecting part is configured to select the first prospective speed as the speed limit when the first regulated speed is greater than the second regulated speed, and

the speed limit selecting part is configured to select the second prospective speed as the speed limit when the second regulated speed is greater than the first regulated speed.

5. The excavation control system recited in claim **4**, wherein

the plurality of driven members include a boom rotatably attached to the vehicle main body,

the plurality of hydraulic cylinders include a boom cylinder for driving the boom, and

each of the first regulated speed and the second regulated speed corresponds to a regulated speed for the extension/contraction speed of the boom cylinder.

6. The excavation control system recited in claim **4**, wherein

the plurality of driven members include a boom rotatably attached to the vehicle main body and an arm coupled to the boom and the bucket,

the plurality of hydraulic cylinders include a boom cylinder for driving the boom and an arm cylinder for driving the arm, and

each of the first regulated speed and the second regulated speed corresponds to a target speed for extension/contraction speeds of the boom cylinder and the arm cylinder.

7. The excavation control system recited in claim **3**, further comprising

an operating tool configured to receive an operator operation to drive the working unit, the operating tool being configured to output an operation signal in accordance with the operator operation, wherein

the relative speed obtaining part is configured to obtain the first relative speed and the second relative speed based on the operation signal.

8. The excavation control system recited in claim **3**, wherein

the relative speed obtaining part is configured to obtain the first relative speed and the second relative speed based on sum of extension/contraction speeds of respective ones of the plurality of hydraulic cylinders.

9. The excavation control system recited in claim **1**, wherein

the speed limit selecting part is configured to select the speed limit based on the first distance and the second distance.

10. The excavation control system recited in claim 9, wherein

the speed limit selecting part is configured to select the first prospective speed as the speed limit when the first distance is less than the second distance, and

the speed limit selecting part is configured to select the second prospective speed as the speed limit when the second distance is less than the first distance.

11. A construction machine, comprising:

the vehicle main body; and

an excavation control system including a working unit formed by a plurality of driven members including a bucket, the working unit being rotatably supported by a vehicle main body,

a plurality of hydraulic cylinders configured to drive the plurality of driven members,

a prospective speed obtaining part configured to obtain a first prospective speed and a second prospective speed, the first prospective speed depending on a first distance between the bucket and a first designed surface indicating a target shape for an excavation object, the second prospective speed depending on a second distance between the bucket and a second designed surface indicating the target shape for the excavation object, the second designed surface being different from the first designed surface, the first designed surface and the second designed surface being disposed adjacent to each other,

a speed limit selecting part configured to select either of the first prospective speed or the second prospective speed as a speed limit based on a relative relation between the first designed surface and the bucket and a relative relation between the second designed surface and the bucket, and

a hydraulic cylinder controlling part configured to limit a relative speed of the bucket to the speed limit, the relative speed being relative to either one designed surface of the first and second designed surfaces which is a target of the speed limit.

12. The excavation control system recited in claim 1, wherein

the hydraulic cylinder controlling part limits the relative speed of the bucket to the speed limit when at least a portion of the bucket is within a region defined by the first designed surface, the second designed surface, and a speed limitation intervening line, the speed limitation intervening line being positioned away from each of the first designed surface and the second designed surface at a prescribed line distance.

13. The excavator control system recited in claim 1, wherein

the first distance is obtained in a direction perpendicular to the first designed surface and the second direction being obtained in a direction perpendicular to the second designed surface.

14. The excavator control system recited in claim 1, wherein

the first distance and the second distance are both distances of the bucket above the first and second designed surfaces, respectively.

15. The excavator control system recited in claim 13, wherein

the first distance and the second distance are both distances of the bucket above the first and second designed surfaces, respectively.

16. The excavator control system recited in claim 1, wherein

the first designed surface and the second designed surface are non-parallel to each other.

17. The excavator control system recited in claim 1, wherein

the second designed surface extends from an end of the first designed surface.

18. The excavator control system recited in claim 17, wherein

the first designed surface and the second designed surface are non-parallel to each other.

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